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Optimisation of the Daily Nutrient Composition of Daily Intakes During Gestation

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Summary

An appropriate lifestyle and diet of pregnant woman during prenatal development contribute to the proper development of a foetus. Since the third month of pregnancy, physical activity should follow the metabolic needs. In this paper, linear programming has been applied in meal planning according to the guidelines recommended for women aged 19 to 30, with emphasis on nutrient intake during all nine months of pregnancy. Data used as the nutritional composition are based on the seven-day supply, where each day consisted of 4 meals; breakfast, lunch, dinner and snack. Linear optimization was carried out using the LINDO program. The program included 28 variables and 20 constraints; energy, water, proteins, fats, carbohydrates, cholesterol, dietary fibres, vitamins soluble in fats; A, D, water-soluble vitamins, B_1, B_2, niacin, B_6, folic acid, B_{12}, C, and minerals; calcium, iron, magnesium, and sodium. The results show that well-balanced, diverse and regular diet can be offered for pregnant woman based on prescribed guidelines providing adequate amounts of nutrients without taking additional supplements. The sensitivity analysis indicated that the menu planning has some limitations regarding the chosen foods in a weekly menu. Especially in the 3rd trimester it is important to include foods rich with folic acid, magnesium and iron.

Key words: optimisation, pregnancy, menu planning

Sažetak

Primjerene životne navike i prehrana trudnice tijekom prenatalnog razvoja doprinose pravilnom razvoju ploda. Budući da do trećeg mjeseca trudnoće mozak fetusa poprima temeljni ustroj, a već u trećem mjesecu počinje i fizička aktivnost fetusa unos nutrijenata trebao bi pratiti metaboličke potrebe trudnice. Smanjen ili prekomjeran unos vitamina i drugih nutrijenata povezan je s različitim urođenim poremećajima i značajno utječe na prenatalni razvoj i postporođajni život. U ovom radu primijenjeno je linearno programiranje u planiranju prehrane prema smjernicama preporuka za žene između 19 i 30 godina s naglaskom na prehranu tijekom tri tromjesečja trudnoće. Korišteni su podaci o nutritivnom sastavu sedmodnevne ponude, u kojem se svaki dan sastoji od 4 obroka; doručak, ručak, večera i međuobrok. Linearno optimiranje provedeno je primjenom LINDO programa. Program je sadržavao 28 varijabli i 19 ograničenja; energija, voda, proteini, masti, ugljikohidrati, kolesterol, prehrambena vlakna, vitamini topivi u mastima; A, D, vitamini topivi u vodi; B_1, B_2, niacin, B_6, folat, B_{12}, C, te minerali; kalcij, željezo, magnezij, i natrij. Rješenja pokazuju da se od navedene ponude mogu složiti dnevne ponude za trudnice bilo kojeg tromjesečja i da slijedeći dobro izbalansiranu, raznoliku i uravnoteženu prehranu tokom cijele trudnoće i držanjem propisanih smjernica, može osigurati adekvatna količina svih hranjivih tvari trudnici i plodu bez uzimanja dodatnih suplemenata. Analiza ponuđenih jelovnika ukazuje kako promatrati samo energetski i makronutritivni unos nije dovoljno, već je vrlo važno promatrati i mikronutritivni sastav ponude, a ključne namirnice u ponudi trudnica moraju obilovati folatima i magnezijem.

Ključne riječi: optimiranje, trudnoća, planiranje prehrane

Introduction

Today is well-known that a healthy lifestyle and diet can be used in prevention of today's deadly chronic degenerative diseases (Mahan and Escott-Stump, 2007). Human nutrition should meet some basic settings: (i) contain sufficient amounts of energy, and (ii) containing all necessary nutritional and protective substances in accordance with the dietary needs of individuals or population groups, in order to ensure a balance between foods that are easily digestible and provide a feeling of fullness and satisfaction after taking meals. Intakes of nutrients that are much higher or lower than recommended can increase the risk of development of chronic illnesses such as coronary heart disease, diabetes, cancer, obesity etc. (IM, 2005). Numerous countries have developed nutrient-based recommendations to improve the nutritional status of their populations and to reduce the risk of chronic diseases (IM, 2003; Martin, 2003; Maillot et al., 2010). In order to design nutritionally adequate diets for individuals, one should be able to simultaneously take into account specific nutritional needs and individual food preferences (Brug et al., 2003) like for instance pregnant women. Numerous studies have shown inadequate nourishment – high intake of refined sugars and fats and insufficient intake of needed proteins, iron and fibres (Kaiser and Allen, 2002; Mungen, 2003). Regarding the micronutrients, some studies show that in the diet of pregnant women often are missing four vitamins: folic acid, vitamin B6, and vitamins D and E (IM, 1998, Scholl and Johnson, 2000). The emphasis in the diet of pregnant women is meeting the needs of the vitamins and minerals, and not just the energy needs (Kaiser and Allen, 2002). The energy needs increases during pregnancy, as shown in table 1.

It is important that their diet is regular and balanced, divers, abundant with fruits and vegetables. If any segment of the diet is ignored, it is possible that for unborn child may not be ensured sufficient amounts of proteins, vitamins and minerals that are needed (Finn, 1997; IM, 1990; Toutain et al., 2010;

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Table 1. *Estimates of daily energy requirements during pregnancy (IM, 2005*

Energy	EER = 354–(6.91xA [y])+PA x{(9.36 x BM [kg])+(726 x BH [m])}
Energy needed	1st trimester => EER = EER (as non-pregnant woman)
	2nd trimester => EER = EER (as non-pregnant woman) + 340
	3rd trimester => EER = EER (as non-pregnant woman) + 452

EER–Estimated Energy Requirement (kcal); A – age; BM – body mass; BH – body height; PA – physical activity

IM, 2003; Swensen et al., 2001; IM, 2005; Vause et al., 2006). According to the authors Mahan and Escott-Stump (2007), the ratios of macronutrients during pregnancy does not change and remain 10-15% of proteins, 30% of fats and 55-60 % of carbohydrates from the total daily energy intake.

The aim of this work was to A) plan and B) analyse diets for all trimesters of pregnancy in order: i) to analyse the possible necessity of oral intake of some vitamins or minerals and, ii) to analyse if the diets during trimesters will be similar or considerably different.

In solving problems that have one goal, and include a large number of data and information, application of computer plays a crucial role. In this paper, linear optimization was applied because it allows to search for a solutions that has one goal (e.g., economically acceptable daily offer), where the result should be a daily offer that must meet a number of constraints for e.g. energy and nutritional constraints (Gajdoš et al., 2001). Linear programming is designed to address the problem by choosing between several possible or available variables in order to achieve the most suitable combination of the selected (optimal) result (Kalpić and Mornar, 1996; Deb, 2001, Darmon et al, 2002; Brown, 1966). Applying these premises (goal and constrains), models were constructed in order to find the so called – optimal solution. Models containing such target function and a set of admissible constrains are called linear models (Eckstein, 1967; Martić, 1996; Kalpić and Mornar, 1996) and are often used in menu planning (Gajdoš et al., 2001; Koroušić Seljak, 2009). Using linear optimisation in menu planning, it is very important to indicate the upper and lower limits, i.e. minimum and/or maximum value that is needed to satisfy the daily nutrition needs (Bhatti, 2000):

Minimum ≤ **acceptable** nutrient amounts ≤ **Maximum** (1)

Nutrient needs are often defined in ranges as mentioned in eq. 1) what will be in detail explained in materials and methods (especially in table 2 and figure 1).

Materials and Methods

The target group were pregnant women aged 19-30. For them was the nutrient composition of the daily intake analysed and planed following the flow chart presented on fig. 2.

Basic guidelines for balanced energy and nutrient intake are the daily recommendations (NN, 2004; IM, 1990; IM, 2005) that define recommended daily needs of energy (table 1), water as well as macro and micronutrients (table 2 and 3).

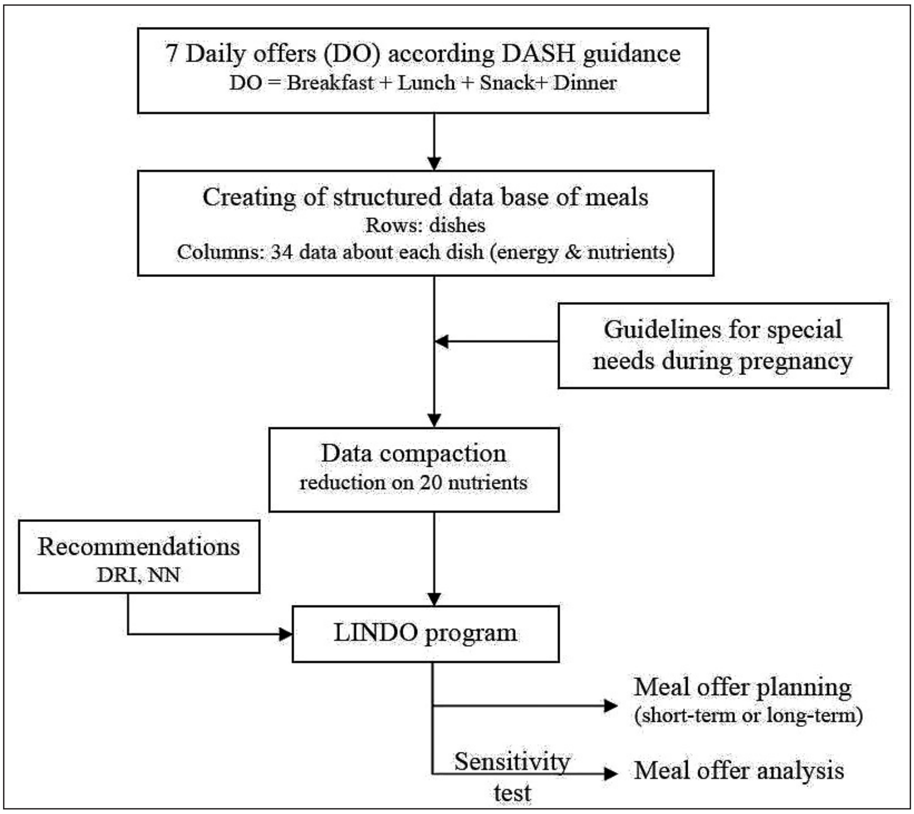

Figure 1. *Flow chart of the methodology used in modelling and optimisation of meal offers for women during pregnancy.*

Database of meals with nutritional content is created in Excel using the USDA database rel. 22 (USDA, 2009) based on 7 days menus taken from the official site of the American Institute of Heart, Lung and Blood (NHLBI, 2010). It is assumed that seven-day menu suggested by NHLBI according guidelines of DASH diet is properly conceived and would be acceptable also for pregnant women regarding the average daily energy offers ranged from 8700 – 10500 kJ (2078-2508 kcal). Menu offer for each day was constituted of one breakfast (B), lunch (L), snack (S) and dinner (D). The data basis contained information, for each dish, of the mass of food, energy, water, content of proteins, fats, carbohydrates, MUFA, PUFA, SFA, cholesterol, dietary fibres, fat-soluble vitamins A, E, K, D, vitamins soluble in water: B_1, B_2, niacin, pantothenic acid, B_6, folic acid, vitamin B_{12}, vitamin C, and minerals: calcium, iron, magnesium, phosphorus, copper, zinc, copper, manganese, selenium, sodium and potassium.

Given that the target group are pregnant women aged 19-30, it was important, from a set of data (34 data for each dish) choose those items that are crucial. That implies reduction of monitored nutrients because some nutrients are more important during the pregnancy.

It was decided to reduce the number of observed data per one meal from 34 to 20 as follows: energy, water, proteins, fats, carbohydrates, cholesterol, dietary fibres, vitamins soluble in fats; A, D, vitamins soluble in water; B_1, B_2, niacin, B_6, folic acid, B_{12}, C, and minerals, calcium, iron, magnesium, and sodium.

The aim is to reach a result that presents a daily energy and nutritive balanced offer with minimal cost. Price was placed in the aim function of the linear model and energy, water and 18 nutrients (proteins, fats, carbohydrates, dietetic fibres, cholesterol, Ca, Mg, Na, Fe, folic acid, niacin, vitamins: B_1, B_2, B_6, B_{12}, A, D and C) were included in the constrains subjected to the goal function, as follows in the basic linear model.

Table 2. *Daily nutrient needs during pregnancy (NN, 2004; IM, 2005)*

Nutrients	***Daily recommendations during pregnancy***	
	Minimum	**Maximum**
Vitamin A (μg)	550	3000
Vitamin B_1 (mg)	1.4	4
Vitamin B_2 (mg)	1.4	4
Vitamin B_6 (mg)	1.9	6
Vitamin B_{12} (μg)	2.6	9
Niacin (μg)	18	35
Folic acid (mg)	600	700
Vitamin C (mg)	85	500
Vitamin D (μg)	10	10
Calcium (mg)	1000	1500
Iron (mg)	27(22)*	30
Sodium (mg)	500	1800 (2000)*
Magnesium (mg)	350	600
water (ml)	1500	2000
Cholesterol* (mg)	/	300

Table 3. *Recommended intake of energy and macronutrients that differ as reflection of the pregnancy trimester (IM, 2005).*

	Dietary reference intake during pregnancy*		
	1st trimester	**2nd trimester**	**3rd trimester**
Energy (kcal)	2000	2350	2500
Proteins (g)	> 50	> 59	> 63
Fats (g)	< 67	< 78	< 84
Carbohydrates (g)	225 – 300	265 – 350	280 – 375
Total Fibres (g)	28	33	35

Basic structure of the linear model:
Goal function:

$$\min F = c_1 \cdot B_1 + ... + c_7 \cdot B_7 + c_8 \cdot L_1 + .. + c_{14} \cdot L_7 + c_{15} \cdot S_1 + .. + c_{21} \cdot S_7 + c_{22} \cdot D_1 + ... + c_{28} \cdot D_7 \quad (2)$$

Constrains that will restrict energy and nutrient content of daily offers:

$$a_{ij} \cdot B_j + a_{ij} \cdot L_j + a_{ij} \cdot S_j + a_{ij} \cdot D_j \geq b_{i,\ \min} \quad (3)$$

$$a_{ij} \cdot B_j + a_{ij} \cdot L_j + a_{ij} \cdot S_j + a_{ij} \cdot D_j \leq b_{i,\ \max} \quad (4)$$

Where:

c_j - Meal price

x_j - Meals, number of the meals (j), j=1, ... , 7

a_{ij} - Content of energy, water or nutrients, i, i=1, 2, . . ., 20, for observed meals, j

b_i - Recommended intakes of energy, water or nutrients

Regarding the fact that pregnancy is divided into trimesters, three different linear programs were created to obtain different offers that will satisfy requirements during all trimesters of pregnancy.

Each daily offer included one breakfast (B), lunch (L), snack (S) and dinner (D). So, the data basis of meals was build up of 28 dishes (7 B x 7 L x 7 S x 7 D) and an ideal case result would be 2401 daily offers. But using the optimisation tools, it will be cleared if all combinations (daily offers) are well balanced concerning the required energy and nutrient content. The aim was also to examine whether women through menu offers will satisfy all energy and nutrient needs without additional supplementation. In order to identify the critical variables (individual meals) or constrains (nutrient requirements), the sensitivity test was used.

For all meals were calculated the costs (based on the ingredients concerning also the preparations costs). According the constructed data basis of meals for pregnant woman, the average values (and prices) are given in table 4.

Results and Discussion

The optimisation was conducted based on recommendations and restriction for nutrients and energy described earlier (tables 1 – 4). The results are daily offers that include breakfast (B), lunch (L), snacks (S) and a dinner (D). According to the required parameters, optimal daily offers for pregnant women for all trimesters were required. The results of the average offers are presented in Table 5.

Table 4. *Calculated average values of meals with average energy and nutrient content and meal prices.*

	$\bar{x}$ (min – max)			
	Breakfast	**Lunch**	**Snack**	**Dinner**
Energy (kcal)	**605.8** (451 – 1053)	**499.2** (334– 646)	**563.3** (323– 824)	**559.8** (313 – 803)
Proteins (g)	**21.8** (16.8 – 36.4)	**36.0** (17.2 – 45.5)	**21.0** (10.2 – 35.6)	**29.2** (14.6 – 46.8)
Fats (g)	**11.7** (5.8 – 26.1)	**13.3** (7.3 – 18.1)	**19.5** (4.5 – 27.2)	**16.4** (8.2 – 34.4)
Carbohydrates (g)	**103.3** (58.6 – 168.1)	**58.7** (41.3 – 89.1)	**75.9** (40.4 – 117.1)	**73.7** (45.1 – 85.7)
Total Fibre (g)	**9.0** (4.3 – 15.9)	**8.1** (5.4 – 12.0)	**5.9** (0.1 – 11.0)	**9.7** (4.9 – 15.4)
Vitamin A (µg)	**293.9** (152.4 – 413.8)	**372.3** (35.6 – 1099.3)	**337.8** (54.0 – 509.6)	**408.9** (130.6 – 1328.5)
Vitamin B_1 (mg)	**0.5** (0.2 – 0.8)	**0.5** (0.3 – 0.7)	**0.2** (0.1 – 0.4)	**0.4** (0.2 – 0.5)
Vitamin B_2 (mg)	**0.9** (0.7 – 1.1)	**0.4** (0.1 – 0.9)	**0.8** (0.2 – 1.6)	**0.4** (0.2 – 0.6)
Vitamin B_6 (mg)	**0.8** (0.3 – 1.2)	**0.6** (0.4 – 0.8)	**0.3** (0.1 – 0.6)	**0.7** (0.2 – 1.2)
Vitamin B_{12} (µg)	**1.8** (1.1 – 2.7)	**1.9** (0 – 9.4)	**1.6** (0 – 3.2)	**1.1** (0.2 – 2.1)
Niacin (µg)	**15.8** (11.5 – 19.6)	**12.4** (10.2 – 13.6)	**8.1** (5.1 – 12.7)	**8.9** (4.4 – 10.9)
Folic acid (mg)	**189.9** (151.0 – 251.5)	**185.8** (148.6 – 249.0)	**150.0** (126.7 – 178.2)	**173.2** (30.9 – 97.2)
Vitamin C (mg)	**57.5** (8.8 – 94.6)	**45.3** (12.0 – 112.4)	**5.4** (0.3 – 19.5)	**34.5** (5.5 – 65.7)
Vitamin D (µg)	**2.8** (0 – 4.0)	**0.7** (0 – 2.9)	**1.8** (0 – 6.0)	**1.6** (0.1 – 4.0)
Calcium (mg)	**452.5** (366.0 – 563.2)	**248.7** (68.3 – 394.5)	**493.9** (89.9 – 1031.6)	**303.7** (169.8 – 419.4)
Iron (mg)	**4.8** (1.5 – 9.6)	**13.1** (9.1 – 16.7)	**2.4** (0.9 – 3.6)	**3.1** (1.1 – 5.7)
Sodium (mg)	**377.7** (197.4 – 511.4)	**820.3** (550.2 – 1234.0)	**250.0** (113.4 – 576.7)	**541.4** (375.3 – 797.8)
Magnesium (mg)	**152.7** (94.5 – 245.1)	**112.6** (89.4 – 138.6)	**125.6** (48.6 – 184.1)	**150.1** (63.1 – 221.3)
Water (ml)	**489.1** (334.8 – 640.3)	**382.8** (244.5 – 681.1)	**342.4** (111.5 – 791.0)	**384.7** (313.2 – 465.1)
Cholesterol (mg)	**14.9** (12.2 – 21.2)	**47.7** (5.3 – 81.6)	**16.6** (0 – 37.7)	**53.2** (12.2 – 106.7)
Price (kn)	**4.3** (2.9 – 6.1)	**14.2** (10.5 – 16.0)	**2.4** (1.5 – 3.0)	**12.9** (8.3 –17.1)

Table 5. *Average composition of optimised offers for pregnant women (± SD).*

	Average content in the daily menu		
	1st trimester	2nd trimester	3rd trimester
Energy (kcal)	2101.1 ± 80.5	2294.1 ± 81.3	2411.3 ± 84.5
Proteins (g)	96.9 ± 2.9	118.2 ± 2.9	122.8 ± 3.6
Fats (g)	56.1 ± 0.3	62.2 ± 5.5	63.6 ± 3.5
Carbohydrates (g)	291.8 ± 15.4	315.4 ± 22.1	337.0 ± 25.4
Total Fibres (g)	31.2 ± 5.2	31.9 ± 4.8	31.7 ± 3.9
Vitamin A (μg)	1262.8 ± 74.2	1791.3 ± 134.6	1111.0 ± 73.5
Vitamin B_1 (mg)	1.3 ± 0.1	1.7 ± 0.2	1.8 ± 0.1
Vitamin B_2 (mg)	2.2 ± 0.1	2.7 ± 0.1	2.5 ± 0.3
Vitamin B_6 (mg)	2.2 ± 0.1	2.3 ± 0.9	2.9 ± 0.1
Vitamin B_{12} (μg)	7.9 ± 6.3	6.4 ± 1.7	6.5 ± 2.5
Niacin (μg)	22.1 ± 3.5	23.2 ± 2.3	23.1 ± 3.8
Folic acid (mg)	639.4 ± 12.6	608.0 ± 81.9	660.1 ± 8.2
Vitamin C (mg)	85.4 ±50.4	153.4 ± 59.9	181.8 ± 19.7
Vitamin D (μg)	7.1 ± 2.6	6.6 ± 1.2	7.4 ± 0.4
Calcium (mg)	1488.5 ± 63.3	1345.1 ± 81.4	1365.8 ± 172.1
Iron (mg)	27.3 ± 0.9	26.6 ± 8.1	26.5 ± 5.5
Sodium (mg)	1802.9 ± 125.7	2153.0 ± 52.8	2108.6 ± 10.0
Magnesium (mg)	486.7 ± 83.1	572.6 ± 52.5	584.3 ± 35.9
water (L)	1548.7 ± 273.6	1649.9 ± 394.9	1504.6 ± 189.4
Cholesterol (mg)	103.6 ± 29.2	147.0 ± 21.4	149.1 ± 24.4
Acceptable daily meal offers	**63**	**45**	**4**

The nutrient compositions of daily intakes were based on restrictions selected with respect to the target group pregnant woman aged 19-30 with the emphasis to the trimesters of gestation. Based on the composition, weekly plan have been proposed that consisted of 4 meals distributed during the day as breakfast, lunch, snack and dinner. The average values of energy and nutrients are presented in table 5. Although from one weekly offer could be combined new 2401 daily menu combinations - analysis shows that only few combinations (4 daily offers) satisfy all the observed energy and nutritional needs during the third trimester (Table 5), while for the first trimester without problems were composed menu offers for almost 2 months (even 63 daily offers satisfied all demands on energy and nutrients).The present study combines the limitations of menu offers (NHLBI, 2010) and of modelling approaches. In particular, the validity of results obtained with diet modelling analysis is dependent on how well the models simulate reality and on the quality of input data.

Studies have proven that linear programming is the ideal tool to rigorously convert precise nutrient constraints into food combinations (Dantzig, 1990; Briend et al., 2003). Until now, it has been used to design either individual diets (Soden and Fletcher, 1992; Colavita and D`Orsi, 1990) or population diets (Maes et al., 2008; Carlson et al., 2007; Cleveland et al., 1993; Darmon et al., 2002) and their implications in terms of food choices (Ferguson et al., 2006).

As some studies show (Carlson et al., 2007; Murphy and Britten, 2006; Katamay et al., 2007; Cleveland et al., 1993; Soden and Fletcher, 1992) that the main goal of linear programming used in meal planning is to reach the nutrient-based recommendations but also to translate the set of nutrient-based recommendations into foods (not food composites) for each individual or group that is a representative sample of the target population (Maillot et al., 2010).

To detect critical points regarding observed meals and constrains the sensitivity test was used in order to deduct the critical points (Gajdoš et al., 2001). The results of the sensitivity test, conducted on the observed constrains, show that minor daily menu offers for the 3rd trimester are affected by the increase of macronutrient needs and in the weakly offer are not offered foods that could at the same time (a) reach the higher protein needs and at the same time not to overload the recommended intake of sodium and (b) be rich with folic acid, magnesium and iron.

Conclusions

From one weekly offer undertaken from NHLBI (2010) that consisted from 7 daily offers from 4 dishes (breakfast, lunch, snacks, and dinner) was possible to gain 2401 daily offers but using the optimisation approach it was shown that it is not possible to combine all dishes in new a daily offers because the nutrient composition will not satisfy needs of the target group, pregnant woman aged 19-30 with the emphasis to the trimesters of gestation.

In accordance with the aims of this work; plan and analyse diets for all trimesters of pregnancy the use of optimisation approach has been a step forward in nutrition planning but based on the energy and nutrient composition it was not possible to offer a new weekly menu for all trimesters. From possible 2401 daily offers (new daily menus) the final menu set was reduced on 63 daily offers for the 1st trimester, 45 daily offers for the 2nd trimester falling on just 4 acceptable daily offers that are in accordance with the recommendations of the 3rd trimester. Each weekly plan that has been proposed consisted of 4 meals distributed during the day as breakfast, lunch, snack and dinner, so for the 1st trimester was possible to offer 9 new weekly offers, for the 2nd trimester the menu set has reduced to 6 weeks offers and for the 3rd trimester, the menu set decrease to 4 daily offers what is insufficient to provide at least one weekly offer. This indicates the limitation of the optimisation approach regarding the input data set, the weekly offer undertaken from NHLBI (2010).

The advantages of linear programming in diet planning regarding the possibility of working with a large number of variables and unlimited number of constraints for an arbitrary period of time was validated. Also, the use of the sensitivity test is possible to detect critical points in the optimisation and to plan strategies in order to evade the poor nutrition. The results indicate that during the 1st and 2nd trimester the optimal offers are well balanced and can provide an adequate amount of nutrients without taking additional supplements in the form of pills, powders or juices. But during the 3rd trimester, the foods offered in the weekly menu plan are incompatible with the needs. In the meal plans should be added foods rich on proteins, folic acid, magnesium and iron with slight content of sodium what was cleared using the sensitivity test.

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